MULTISENSOR ANALYSIS FOR SOILS MAPPING

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by

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and
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Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Technical Paper

MULTISENSOR ANALYSIS FOR SOILS MAPPING

To: G. A. Leonards, Director
Joint Highway Research Project

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From: H. L. Michael, Associate Director
Joint Highway Research Project

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The attached Technical Paper "Multisensor Analysis for Soils Mapping" authored by Harold T. Rib and Robert D. Miles was presented at the 1968 Annual Meeting of the Highway Research Board in Washington, D. C. It has been offered for publication.

The paper is a discussion of the investigations conducted by Mr. Rib and reported in his research report for the HPR project "Annotated Aerial Photographs as Master Soil Plans." Approval of this research report has been received from the ISHC and Bureau of Public Roads.

In preliminary discussions with the publisher, the Highway Research Board, Plates 1A and 1B would be combined into a single fold out, Plate 1. This plate should be in color to show the advantages of color photography. Publication in black and white would not be satisfactory for the purposes of this paper. The cost of publication of Plate 1 in color is an estimated $650 more than in normal black and white and the Highway Research Board requires that this extra cost be borne by the author or his sponsor. It is recommended, therefore, that the paper be approved for publication by the Highway Research Board and that the extra $650 for publication in color of Plate 1 be paid by funds from the HPR research project "Annotated Aerial Photographs as Master Soil Plans."

Respectfully submitted,

Harold L. Michael
nf

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HLM:nf

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MULTISENSOR ANALYSIS FOR SOILS MAPPING

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INTRODUCTION

Within recent years, new remote sensors, such as, infrared, radar, multichannel and multiband instruments have become available to civilian organizations. In addition, newer and improved aerial films have been made available and special film-filter combinations for image enhancement have been evaluated. Several studies have been performed where each of these new sensors and film types have been evaluated individually; however, little has been reported in the "unclassified" literature on the evaluation of combinations of these films and sensors.

To investigate the potential of these aerial films and sensors for detailed soils mapping, a project was instituted at Purdue University entitled "Annotated Aerial Photographs as Master Soils Plans." The first

phase of this project was to evaluate the potential of the available types of aerial sensors and to propose a multisensor system for performing detailed engineering soils mapping. This phase was completed in December 1966 (1) and is the subject of this paper.

FLIGHT PROGRAM

To investigate the applicability of the various remote sensors for obtaining soils information, three test sites were selected in the vicinity of Purdue University. A total of nine flight coverages were obtained over the three sites during a period from May 1965 to June 1966. Concurrently with the aerial program, a field program was conducted to evaluate some of the parameters influencing the data collected and to determine some of the conditions existing during the flight coverage.

Field data collected during the program included: (1) surface soil moisture contents; (2) photographic and multiband ground coverage; (3) field radiometer readings in the 8-14 μ band; and (4) meteorological data from local weather stations.

A summary of the flight programs, type of coverage and organizations flying the coverage are listed in Table 1. As noted in the table, five different types of aerial photography (flown at three different scales) multiband photography, infrared imagery (three different sensor systems) radar imagery (two different sensor systems) and multispectral imagery (ultraviolet through far infrared) were obtained. Although, during any given flight program, simultaneous exposures of all film types and sensors were not obtained, sufficient combinations of sensors were evaluated in the combined program to arrive at an optimum system for soils mapping.

EQUIPMENT AND VIEWING TECHNIQUES

Stereoscopic coverage was obtained for all aerial photographic film types. The viewer used was a Zoom Stereoscope capable of continuous magnification from 2.5 to 20 times in two stages. The stereoscope was mounted on a microscope carriage on a light table enabling scanning in an X and Y direction. The light source was an argon-mercury source which provided 900 foot lamberts at maximum intensity and permitted a continuous variable intensity at a 20 to 1 ratio in two overlapping ranges. Both transparencies (positives and negatives) and positive prints were viewed on the light table. To view the positive prints, the prints were secured on the table and illuminated by an external source.

Two techniques were utilized in the analysis of the photography which assisted in the interpretation. Special Wratten filters were used in the viewing system when interpreting the color photography and backlighting was used when viewing positive prints on the light table.

The use of special filters was found to increase the contrast between objects of interest on the color photography and made it possible to delineate various soil boundaries more easily. The filters utilized were Wrattens 25, 47 and 58; the same filters as were used in a reflection densitometer. The densitometer was used to determine the filter that gave maximum contrast and this filter was used for interpretation of the photography. It was found that by using one filter it was possible to obtain the desired contrast without excessive suppression of light.

The use of backlighting for viewing positive prints on the light table was found to be very helpful. It decreased the glare obtained

from the surface of the print and at low backlighting levels, it appeared to increase the contrast between objects. This increase in contrast was not a continuous effect but appeared to decrease as the amount of backlighting was increased.

STUDY APPROACH

The approach used in this multisensor study was an attempt to identify various soils and rock units through their unique responses in various portions of the electromagnetic spectrum. For example, their properties of reflectance of solar energy in the visible region, their emittence properties in the infrared region, or the amount of transmitted signal energy they reflect back to the antenna in the radar region. This approach is not straightforward since information on soils is not directly observable on photography or imagery. It is interpreted by deduction and inference based on the evaluation of the pattern elements of "form" and "tone and texture" (2). Form includes the elements of topography, drainage and erosion. The elements of "tone and texture" include the values and textures related to land use and vegetation and the tones related to materials (3).

The qualitative analysis of the data collected for the determination of a system for soils mapping was based on the premise that an optimum system would be one which had the greatest potential for evaluating the pattern elements. The potential of the various film and imagery types studied was evaluated by comparison to black-and-white photography, the standard type heretofore used for soils mapping.

In analyzing the data, the elements of form and tone and texture (largely those of tone) were discussed separately where it was possible to separate these items. To simplify reference to the various film types and prints discussed, the following symbols will be used throughout in lieu of the film name.

Black-and-white photography	B & W
Black-and-white infrared photography	B - I
Color transparencies (positives)	C - P
Color negative film	C - N
Color infrared transparencies (positives)	C - I
Color print made from color negative	C - P/C - N
Black-and-white print made from color negative	B & W/C - N

ANALYSIS OF ELEMENT OF TONE

Comparison of Film Types

The element of "tone" is very important in the interpretation and delineation of soils. The major factors contributing to the tonal patterns on aerial photography, as indicated by Rib (1), include: (1) color of soil and rocks; (2) composition of soil and rocks; (3) moisture condition of soil and rocks; (4) culture; and (5) vegetation. Therefore, an important step in soils interpretation is the discrimination of tones due to soil composition from tones due to the other factors.

The value of the various film types for discriminating between the major tonal factors is demonstrated in Plate 1. The area covered is in a transitional zone between soils developed under prairie cover and those developed under forest cover. The parent materials are the same in both areas. In the field, it is observed that the soils derived under

prairie conditions have darker intrinsic soil colors and higher organic contents.

The comparison of the various film types for distinguishing between the tonal factors indicates that natural color film (C - P or C - P/C - N) has the advantage over the other types. This is demonstrated by comparing points 1 through 6 on the various film types. On C - P, the presence of natural color tones make it possible to distinguish between glacial till soils developed under forest cover (vicinity of point 1) from those developed under prairie cover (vicinity of point 2) as well as each difference within each of these zones due to topographic position (points 3, 4 and 5). The darker color prairie soils in the vicinity of point 2, can be distinguished because of their overall darker tone commensurate with the darker color of the natural soils. Soil differences due to topographic position are evident by the darker color of the depressional soils due to higher organic content (point 3); the lighter color of the silty surface soils in the topographic high position (point 5); and the orange yellow color of the soils on the eroded slopes (point 4) where the silty clay subsoils are exposed. These differences, significant to soils mapping, are readily distinguished on C - P film. The presence of a slight greenish tinge in the area of point 6 indicates, that in this case, the tonal differences are due to the presence of vegetation just starting to grow and not due to soil differences.

The different tonal patterns noted above are also apparent on C - I and C - N films. However, because of the unnatural or false colors present on these film types, it is difficult to correlate the color differences observed to differences in soil composition. The presence of

vegetation (point 6) is especially distinct on the C - I film due to the reddish tones. This feature is significant if information on vegetation is required.

The analysis of B & W and B - I film types demonstrate the difficulties encountered in soils mapping with these types. In some cases, soils having different intrinsic soil colors appear in the same tone (e.g., points 4 and 5). In many cases, tonal differences are noted on these film types; however, one of the major problems encountered is determining what factors are causing the tonal patterns. For example, are the darker tones in the vicinity of point 6 on B & W due to moisture, soil color, vegetation or soil composition? This can not always be evaluated on B & W alone and thus, may require more field checking.

Highly organic soils are evident on all positive film types by dark tones (above point 7). Points 8, 10 and 11 indicate other soil types and tonal relationships. Point 8 is a high soil area in the prairie glacial till zone, point 10 is a gravel pit area with granular materials exposed and point 11 is an area of glacial till deposits over other deposits. A feature to note in this group is that the granular materials (point 10) are light on all film types except the B - I where it has a medium tone.

Comparison of Infrared Imagery and Aerial Photography

Comparisons of infrared imagery and aerial B & W photography are shown in Figure 1. Comparisons of daytime and nighttime imagery in the 8-14μ band are included in Figure 2. The visible photography included in Figure 1 was taken a month earlier than the infrared imagery. Therefore, some differences in tone may be due to changes in vegetation,

moisture conditions or farm practices during the interim. However, the tonal relationships noted for most of the points selected remained relatively unchanged.

Comparing the 8-14μ band imagery and the visible photography in Figure 1, several tonal relationships are present which are of assistance in separating significant engineering soils and rock units. As noted on the visible photography, the glacial till soils in high topographic position (point 5) have light tones because of their low organic content and predominance of well drained silts. The glacial till depressional soils (point 6) have dark tones because of high organic content, finer texture and darker colored soils. These same areas show a reversal in tones respectively on the infrared imagery. This reversal in the infrared region is due to the fact that the darker colored soils absorb more heat than the lighter colored soils, emit more energy in the infrared region and thus have a lighter tone on the imagery. Another example of tonal reversal is shown by point 1 which is a depressional, dark colored, fine-textured soil in the flood plains.

Other factors can change the tonal relationships present on the imagery. Examples where tonal reversals do not occur for dark, fine-textured soils are demonstrated by points 3, 7 and 10. Point 3 is a muck deposit and points 7 and 10 are soils located in low drainageways in glacial tills. For these soils, the tones are not light on the infrared imagery but medium to dark and for different reasons. The darker tones in areas 3 and 10 are due to a high moisture content while that of point 7 is due to the presence of vegetation. Both of these factors cause a cooling effect on the surface soils thus resulting in

darker tones on the imagery.

Similar variations are noted in light colored soils. Not all light colored soils in the visible are dark in the infrared imagery. Many are light or medium light in the infrared (points 2, 4, 8 and parts of 9). Area 2 is sand, area 4 is shale bedrock covered by thin alluvium, point 8 is a sandstone bedrock and point 9 is a field where sandstone is very shallow. These areas are light for various reasons (specific heat, thermal conductivity, etc.) which can not be evaluated just by comparison of the infrared imagery and visible photography. However, by comparison of tones present on both systems further separations are possible.

Points 11, 12 and 13 were included to show that in daytime infrared imagery, differentiation is difficult between low vegetation, trees and water.

Analysis of imagery in other bands of the infrared region were made but are not illustrated. Comparisons of imagery in the 4.5-5μ band and the 8-14μ band indicated that most of the tonal constrasts seen on the 8-14μ band were evident on the 4.5-5μ band, but were not as distinct. This was anticipated since the peak for the terrain temperatures normally encountered is about 10μ, and thus, the maximum emitted energy would be recorded in the 8-14μ band.

Daytime imagery in several other bands in the middle infrared (1.5-5.6μ) below the 4.5-5.5μ band was investigated. The tonal patterns recorded in these regions were very similar in appearance to the photographic infrared region since solar reflectance and not emitted radiation was sensed. Considering all bands where soils were analyzed, the maximum information was obtained in the 8-14μ band.

Many of the tonal relationships noted in Figure 1 are also present in Figure 2. Comparing the daytime infrared in Figure 2 to the visible photography of the same area (Plate 1), it is noticed that the dark colored depressional soils developed under forest cover (point 3) are lighter on the daytime imagery and the lighter colored high soil areas, (point 4) are darker on the imagery. Similarly, depressional soils in the prairie region are light on the imagery (point 2) and high soil areas are dark (point 8). Granular materials in the gravel pit area (point 10) are a medium tone on the imagery while they are light on the visible photography where exposed. Point 11 shows a uniform light tone on the imagery, even though in the visible there are various soil differences. This change is due to farming practice (recent plowing since visible photography obtained).

Comparison of the daytime to nighttime imagery indicates that certain features are more easily differentiated at night. During the day the tonal difference between low vegetation (point 12), trees (point 13) and water (point 14) are indistinguishable on the imagery. At nighttime, the water appears the lightest, the trees are also light but not as light as the water and the low vegetation remains dark. In fact, an indication of drainageways where water is not flowing can be interpreted from the nighttime imagery (point 15). In this case, the drainageway is dark instead of light.

Differences between soil units, such as those between points 3, and point 4 are still evident on the nighttime imagery but not as clear. The depressional soil, (point 3) is still the lighter. The granular areas (point 10) have become lighter and more distinct on the nighttime imagery.

Comparison of Radar Imagery and Aerial Photography

Radar imagery is developed from an active sensing system; therefore the frequency utilized and the characteristics of the sensor system greatly influence the amount of useful information on soils that is obtained. All radar imagery obtained during this study utilized K-band frequencies. Consequently, the imagery indicated only the influence of surface conditions.

Figure 3 includes an example of radar imagery illustrating horizontal transmission and receiving (HH polarization) as well as horizontal transmission and vertical receiving (HV polarization) covering the test sites. The examples shown are enlargements prepared from unclassified "degraded" imagery obtained on September 14, 1965 through thick cloud cover. Visual photography (B & W) of a portion of the site taken two weeks earlier (September 1, 1965) is included for comparison. Although the "degrading" and enlarging greatly reduced the resolution of the radar imagery, several major features can still be evaluated, (points 1 through 15, Figure 3).

The comparison of the radar imagery obtained by HH polarization to that of HV polarization demonstrates that except for linear oriented objects the only difference noted between the two types is that the HV polarized imagery shows less tonal contrasts than the HH. This is due to the weaker signal return received for HV systems. For tonal contrasts of linear features such as the airport (point 4), buildings (point 5), roads (point 6) and the railroad (point 7) significant differences are noted. The airport and road systems are less noticeable on HV imagery, while the railroad is more noticeable on this type. Although the return from the buildings is much brighter on the HH, the decrease in return makes the building shapes more distinct on the HV imagery.

Major topographic breaks are evident on radar. Point 1 indicates the topographic break between the flood plain and terrace and point 2 the break between the terrace and ground moraine (valley wall). Attempts to distinguish different types of soils on the radar imagery were not successful because of the wavelength of radar used. At K-band frequencies, all soils in the test areas are fine-textured in relation to the length of the radar waves and thus specular (mirror-like) reflection occurs. The radar signal is reflected away from the radar antenna and all soils appear dark on the imagery and can not be separated from other items that produce specular reflection such as water and roads. The dark tones representing various types of soils include areas of sand dunes (point 8) plowed sandy fields (point 9), sands and gravels in gravel pits (point 10), plowed silty loam surface soils on granular terrace (point 11), and plowed silty clay soils in glacial tills, both highs and depressions (point 12). The lighter tones present on the imagery are due in part to the scatter and return of the signal by various types of vegetative cover. For example, the fields with corn exhibits light tones (point 13). Areas covered with trees also show light tones. Pastures and fields with low vegetation have darker tones (point 14).

Special image tones to note on the figure are the light tones present around the gravel pit areas (point 10) and from the ridges in an old gravel pit (point 3). These returns are not due to texture of the material or presence of vegetation, but to geometric relationships similar to conditions reported by Rydstrom (4).

Another image of interest is the point marked "a" in the plowed field (point 11). This feature demonstrates how radar assists in the interpretation of B & W photography. On the B & W photograph, point "a"

is evidenced as a dark tone which could be interpreted as either due to moisture or vegetation conditions. Because of its low topographic position (a drainageway) and no apparent height on stereoscopic examination, one might conclude that the dark tone on the photograph is due to moisture. However, from a study of the radar imagery, the presence of a light tone indicates that there is vegetation in the channel. If the condition was due to moisture, the tone would be dark on the imagery which is typical for water (point 15). This item caused no problem on the color photography obtained at the same time. On the color photography, a greenish color was present at point "a" indicating the presence of vegetation.

Comparison of Multispectral Data

In the previous discussions, comparisons were made between various types of films, infrared and radar imagery. For the examples illustrated, the various types compared were not taken at the same time. This factor contributes to the difficulty in comparing the photography and imagery because of the changes that occur between procurement of these various types. The discussion in this section describes the information obtainable from a multispectral system where photography and imagery are simultaneously obtained in several spectral regions.

Multispectral data was obtained with the University of Michigan multichannel sensor. This sensor simultaneously obtains up to 18 channels of imagery ranging from the near ultraviolet to the far infrared. Unlike the other multisensor systems where images of different scales, resolution and format were obtained, this system provided imagery in all bands at similar scale, resolution and format. This permitted a better

comparison of tonal relationships to be made between channels.

To examine some of the tonal relationships existing for various terrain features, the reflectance of various items was measured in each band with a reflection densitometer. The density values obtained by the densitometer were converted to reflectance by the relationship --

$$\text{Reflectance} = \frac{1}{\text{antilog}_{10}\ \text{Density}} \qquad (1)$$

These values were then normalized for each band by determining the reflectance of the lightest object (R_L) and the darkest objects (R_D) in each band and using these as the one hundred per cent and zero per cent reflectance points respectively. The normalized reflectance (Rn) for each object was then determined by the following method:

$$R_n = \frac{(\text{Reflectance of Object} - R_D)}{R_L - R_D} \times 100 \text{ per cent} \qquad (2)$$

Since both reflectance and emittence were being evaluated, the values plotted were referred to as normalized response. These normalized values were plotted in the respective region of the spectrum and the points connected to obtain a spectral response curve or signature for the various terrain features of interest.

An aerial photographic mosaic showing the conditions existing at the time of the multichannel imagery was obtained and the location and description of the various terrain features measured with the reflection densitometer are shown in Figure 4. Examples of the spectral response signatures obtained for the various target materials are included in Figure 5. These curves are divided into three groups. Figure 5a includes spectral response signatures for bare soils and rock units; Figure 5b includes spectral response signatures for bare soils whose

tones vary from those in Figure 5a due to farming practices; and Figure 5c includes spectral response signatures for various vegetation conditions present in the area. The abscissa representing spectral bands is not plotted to scale. The wave lengths shown at the bottom are only intended to indicate the regions of the spectrum included in each of the spectral bands delineated.

The five bands delineated in Figure 5, (L) light, (ML) medium light, (M) medium, (MD) medium dark, and (D) dark are qualitative ratings. They were used to compare the relative tones on the multichannel imagery to those on other forms of photography and imagery where comparative measurements were not possible.

The spectral response curves in Figure 5a demonstrate the similarities and differences present for sandstone (curve 5), glacial till soils of various topographic positions (curve 9), eroded slope; curve 10, depressional area; curve 11, high topographic position), and a glacial till soil overlain by 4 - 5 feet of loess (curve 1). All of these units can be separated because of distinct differences in various portions of the spectral region. For example curves 1, 5 and 11 are similar throughout the visible region, but curve 5 shows a darker tone than 1 and 11 in the photographic infrared region, while curve 11 shows a darker tone than curves 1 and 5 in the far infrared region. Curves 9 and 10 similarly have distinct differences to aid in separating them from each other and from the other units. The spectral response signatures for the soils and rock units confirms many of the tonal relationships previously noted in comparing various film and sensor types. For example, comparison of glacial till soils (curve 10, depressions and curve 11, highs)

indicatesthat in the visible region, the high soils are light and depression soils are generally medium to medium dark. In the far infrared, there is a tonal reversal and the depression soils are light and high soils dark.

The effect of farm practices on the tones obtained in the various bands is demonstrated in Figure 5b. All of these curves represent soils recently plowed. Curve 4 represents a field plowed a few days before the flight. Curves 3 and 14 represent fields plowed the morning of the flight (flight performed in the afternoon) and curves 2 and 13 represent areas being plowed during the flight or a very short time prior. Soils represented by curves 2, 3 and 4 are glacial till soils predominantly in the high topographic position and those of curves 13 and 14, sandy soils of the flood plains.

The effects of the plowing are to expose at the surface the wetter and darker colored subsoils. When the soil is first turned over, the moisture effect is the controlling factor, resulting in darker tones in all bands regardless of texture (e.g., curves 2 and 13). As these soils dry out, the effect of moisture is decreased and that of soil color becomes prominent (e.g., curves 3, 4 and 14). Note curves 3 and 4 (drying 1/2 day and 2 days, respectively) are fairly similar and both resemble curve 9 (Figure 5a), the eroded glacial till soil, in which similarly, the subsoils are exposed.

The last group of curves in Figure 5c show the differences in spectral response signatures obtained due to various vegetation conditions. Curves 6 and 12 represent fields of winter wheat while curves 7 and 8 represent pasture fields. It is noted that pasture fields can

generally be distinguished from winter wheat by lower reflectance in the photographic IR region. It is further noted that all the curves in this figure indicate that the presence of vegetation results in dark or medium dark tones in all bands but the photographic IR. Since the previous curves for soils indicate that soils have low response in the photographic IR, this is an excellent band for distinguishing tonal effects due to vegetation from those due to soils.

The difference in response between the pasture fields, curves 7 and 8, is that the field containing point 7 has bedrock close to the surface and its influence is indicated by the light streaks in the field (see Figure 4). This affects the overall tonal response resulting in slightly lighter tones. The differences between the fields of winter wheat, curves 6 and 12, are a little more difficult to explain. These curves are failry similar in all bands but the photographic IR. In that band curve 6 is darker. From investigation of this phenomena in the field, it was determined that field 6 was planted two weeks earlier than field 12. In addition, it was discovered that this field had been planted in corn the year before while field 12 had been planted with a low cover crop. It has been suggested by a botanist that the tonal patterns may be reflecting vegetation differences due to varying nitrogen levels in the soils. This could not be verified, but similar effects of previous planting history on variations in tonal patterns obtained for similar crops has been reported by C. E. Olson (5).

One final feature can be noted in reviewing the spectral response curves in Figure 5. Many of the curves for soils (but not all) show a dip in the yellow-orange bands. Thus tonal differences between some

soils are increased in this band. This may explain why it is easier to delineate some soil boundaries on color photography using a red Wratten filter.

The examples discussed in Figures 4 and 5 clearly demonstrate the influence of culture factors (e.g., farming practices) on the final density patterns obtained and the added difficulty in attempting to arrive at diagnostic tonal patterns. Just the matter of plowing the field or the sequence in planting crops affected the tonal patterns obtained. It further points out the need for field control during flights to determine the existing ground conditions. However, these examples show that multichannel imagery does provide a method whereby these various factors can be distinguished. The spectral response signatures obtained by density measurements combined with normalizing procedures demonstrate a valuable method for evaluating the response of various terrain features in different regions of the spectrum from an airborne platform. This should prove to be an excellent method for determining spectral bands of maximum contrast for the separation of features of interest.

ANALYSIS OF ELEMENTS OF FORM

The elements of form are as important in the interpretation of soils and soil conditions as those due to tone and texture, and sometimes more important. To properly evaluate the elements of form, stereoscopic capabilities are generally necessary. This feature limits the use of imagery for interpreting elements of form. However, it does not eliminate these types, as general information on topography, drainage and erosion are often evident on the imagery, either directly or indirectly.

The main comparisons discussed are those for the delineation of drainage patterns and the effect of scale of photography on interpretation of soils. This latter item affects the ability to distinguish features of topography and erosion.

Delineation of Drainage Systems

Drainage conditions were evaluated on the various film and imagery types obtained on the project. For the actual drawing of the detailed drainage system (with proper position and orientation) stereoscopic study was required. This eliminated the imagery as far as preparing the drainage maps, but not with respect to location of drainageways or drainage patterns. Figure 6 shows a comparison of drainage evident on B - I and B & W photography and daytime and nighttime infrared imagery. It is evident from this figure that the creek with all its intricate bends is most easily distinguished on the nighttime infrared imagery than on any of the other types. The details of the creek are least evident on the B & W photograph. Intermediate between these extremes and about equally distinct is the evidence of the creek on the daytime infrared and B - I photograph.

To evaluate the various film types for the purpose of drainage delineation, separate drainage maps were prepared for a selected site from B & W, C - P and C - I film types. B - I was not analyzed as it was considered comparable to C - I for drainage delineation. Results indicated C - P and C - I films provided the most drainage detail and the most confidence in separating perennial and intermittent streams. The detail mapped on B & W was about 90% of that on other two types, the main difference being the confidence in determination perennial or

intermittent nature of the streams. It was noted that the date of the photography was more critical than the type of photography used. For all practical purposes, B & W is satisfactory for preparing the drainage map during the period of the year (May in this case), when the leaves are not on the trees. At other times of the year, when the leaves are out, B - I or C - I are better because the black tones produced by water on these films are more easily distinguished through the tree foliage.

Effects of Scale

The influence of scale of photography on the interpretation of soils is a tenuous item. Since soils are not features that can be directly seen and interpreted on photography, the use of a larger scale does not necessarily insure an increase in soils information interpreted. It is true that at a larger scale, more microfeatures and details can be identified and analyzed, but opposing this, a smaller field of view is obtained and more photographs have to be analyzed for the same area. Several different scales have been reported in the literature for soils mapping ranging from 1:50,000 down to 1:5,000; however, no optimum scale has been reported.

To investigate the effect of scale on soils mapping, two scales of photography were obtained in the 1965 flights and three scales of photography in the May 1966 flight (refer to Table 1). The evaluation of the various types of films at these different scales with respect to soils mapping led to some very enlightening results. It was determined that the optimum scale for performing detailed soils mapping was not just a function of the scale of the photography, but was also a function of the type of film used; and the magnification capabilities of the viewing system (other pertinent items being the same for all film types).

For this project, the viewing system utilized, zoom stereoscope with range of magnification from 2.5X to 20X, was not a limiting factor as all the film types investigated degraded or became uninterpretable before the maximum magnification potential of the viewer was reached. Thus, in the final analysis, the main feature other than scale was film type.

A qualitative rating of the various film types, based on the amount of detail evaluated (function of magnification and contrast) is shown in Table 2. The ratings shown were based on comparisons of the various types to black-and-white photography, used as the average. All films compared were approximately the same scale (1:10,000). Only positive films were considered in the first rating. The second rating shown in this table indicates the relative suitability for image magnification of the various film positives and negatives compared to black-and-white photography (positive print).

In a comparison of the film types, it was observed that the greatest magnification possible, was obtained in viewing the C - P and C - I transparencies. In addition, the various color tones on these types increased the contrast between various objects and their background making it easier to delineate smaller objects. These characteristics enabled more details to be identified from these types than from the other film types studied. In fact, it was noted in an area where soils maps were prepared from the various film types, that approximately equivalent details could be interpreted from small scale color photography (1:24,000) as from medium scale black-and-white photography (1:10,000). Other items noted from Table 2 include: (1) greater magnification (good to excellent) was obtained on the negatives than on prints from them; (2) both B & W and C - P prints made from the color negatives (C - N)

could not be magnified as much as the other types; and (3) the least detail was obtained from the B & W print from the color negative while good detail was obtained from the color print from the color negative because of the increased contrast the colors provided.

SUMMARY AND CONCLUSIONS

This paper reports on a study performed to investigate the potential of available remote sensing systems for the evaluation of soils and soil conditions. To investigate the various sensors, a total of nine aerial flights were obtained over three controlled test sites during the period May 1965 to June 1966. Coverage was obtained with various aerial films (C - P, C - I, C - N, B - I, B & W), a multiband camera, radar sensors (K-band), infrared sensors (4.5-5.5μ and 8-14μ), and a multichannel sensor (rear ultraviolet to far infrared). The various film and imagery types were evaluated individually and in combinations to determine which type or types provided the most information on the pattern elements of "tone" and "form." Since soils are interpreted from an analysis of these pattern elements, the basic premise of the study was that the optimum system for soils mapping would be one which had the greatest potential for evaluating the pattern elements.

Results of this study indicate the following:

1. The results of the comparisons of the different film types taken at different scales and times of the year indicated that for the interpretation and detailed mapping of soils, natural color aerial photography was the most useful <u>single</u> film type. This is due to the greater number of distinguishable color tones present on the color photography and the natural color appearance of the soils and soil conditions. Other

important advantages noted for color photography in comparing the various film types are that (1) smaller details can be identified on color photography than on black-and-white at the same scale, and (2) special filters can be used in analyzing the color films which increase contrast between certain soils and makes soils mapping easier.

2. The optimum scale of photography for soils mapping is a function of film type and magnification capabilities of the stereoscope in addition to flight altitude. Experience in this study with three different scales, indicated that a medium scale photography (1:8,000 - 1:15,000) was the optimum scale for detailed soils mapping. The choice of the lower or higher range of the scale depends on the other two factors.

3. Infrared imagery can not be used as a primary source for engineering soils mapping because of its smaller scale, poor resolution and lack of stereoscopic viewing capabilities. Its primary value is that it provides supplementary information not obtainable by any other means and provides converging evidence which aids in the interpretation of soils and soil conditions. It was found that the 8-14μ band was of greatest value for obtaining information on soil conditions. The 4.5-5.5μ was suitable, but tonal differences were not as distinct.

4. K-band frequency radar was of little value for interpreting soils in the study area. Tonal patterns for exposed soil areas were dark for all soil types at this frequency except for the special case when the radar signal was normal to the surface of the soils. Radar was of some value for evaluating soil conditions (e.g., vegetation, land use) although small scale and poor resolution limited the value of this feature also. The all weather and twenty-four hour capabilities of obtaining

radar (except under conditions of heavy rain or snow) is an advantage of this type over other types analyzed.

5. From the qualitative analysis and evaluation of the various aerial photography and imagery data collected, it is concluded that the optimum system for performing detailed engineering soils mapping, considering the presently available equipment, is one which simultaneously obtains multispectral imagery and color aerial photography. The development of normalized response curves from multispectral data is a powerful tool for evaluating the various tonal factors and determining which bands demonstrate the maximum contrast between soils of interest. For the condition where a multispectral sensor is not available, an alternate system which can be used is one which simultaneously obtains color photography, color infrared photography, and infrared imagery in the 8-14μ band. Detailed soils mapping of equivalent detail and accuracy as the optimum system can be obtained but it requires more field control than the optimum system.

ACKNOWLEDGMENTS

The accomplishment of a project of this complexity could not be completed without the assistance and support of many organizations and persons. The study was sponsored by the Indiana State Highway Commission and the Bureau of Public Roads, Federal Highway Administration, U. S. Department of Transportation. It was performed as a Joint Highway Research Project at the Engineering Experiment Station, Purdue University. Special thanks are due personnel of the various organizations who were especially helpful including: (1) Aerial Photography Section of the Indiana State Highway Commission; (2) Infrared and Optical Sensor Laboratory, Institute

of Science and Technology, University of Michigan; (3) Avionics Laboratory, Wright-Patterson Air Force Base; (4) Northern Forest Fire Laboratory, U. S. Forest Service; and (5) Laboratory for Agricultural Remote Sensing, Purdue University.

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Table 1. Flight Coverage of Test Sites

Date	Photographic Coverage[a,b]						Imagery Coverage[c]			Agency[d]
	B&W	B-I	C-P	C-N	C-I	Nine-Lens[e]	Infrared[f]	Radar[g]	Multichannel[h]	
5/13/65	---	---	m	---	---	---	3	k	---	WPAB
7/1/65	m,l	m,l	m,l	---	---	---	3	k	---	WPAB
7/26/65	---	---	m,l	---	---	---	3	---	---	WPAB
9/1/65	m	---	m,l	---	m,l	---	---	k	---	WPAB
9/14/65	---	---	---	---	---	---	---	k'	---	i
10/7/65	---	---	---	---	---	---	---	k'	---	i
10/25,26/65	m,l	m,l	---	m,l(1)	m,l	m	---	---	---	ISHC
5/2/66	h,m,l	---	---	---	---	---	---	---	---	ISHC
5/3/66	---	---	---	h,m,l(2)	h,m,l	---	---	---	---	ISHC
5/4/66	---	---	h,m,l	---	---	m	---	---	---	ISHC
5/6/66	l	h,m,l	---	---	---	---	---	---	x	ISHC,UM[j]
6/1/66	---	---	---	---	---	---	1,2	---	---	FS
6/2/66	0	---	---	---	---	---	1,3	---	---	FS

a. Film Types and Filters: B&W, Plus-X Aerographic Film: No. 12 antivignetting filter on 10/65 and 5/66 flights.
B-I, Infrared Aerographic Film: No. 12 antivignetting filter on 10/65 and 5/66 flights.
C-P, Ektachrome Aero Film (HF-3 used on 5/13 flight).
C-N, (1) Agfacolor Negative Film CN 17, used Oct. 25-26.
(2) Ektachrome MS Aerographic Film Type SO-51 (Aero-Neg.), used May 3.
C-I, Ektachrome Infrared Aero Film: No. 12 antivignetting filter, on 10/65 and 5/66 flights.

b. Photographic Scales flown, 9 x 9 format:
h - high altitude 1:24,000. m - medium altitude 1:10,000. l - low altitude 1:4,000. 0 - 70mm format, low altitude.

c. All imagery obtained on this project is "classified." Prints from radar imagery of 9/14 and 10/7, 1965 and infrared imagery of 6/1 and 6/2, 1966 have been "declassified."

d. Agency: WPAB - Avionics Laboratory, Wright-Patterson Air Force Base.
ISHC - Indiana State Highway Commission.
UM - Infrared and Optical Sensor Laboratory, Institute of Science and Technology, University of Michigan.
FS - Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, U. S. Forest Service.

e. Nine-Lens camera coverage from .38 to .89 microns in 8 steps.

f. Infrared Imagery: 1. 4.5-5.5 micron band, daytime; 2. 8-14 micron band, nighttime; 3. 8-14 micron band daytime.

g. Radar coverage: k - K band (HH) polarization. k' - K band (HH) and (HV) polarization.

h. Multichannel coverage from ultraviolet through far infrared.

i. Obtained with equipment developed by U. S. Army Electronics Command.

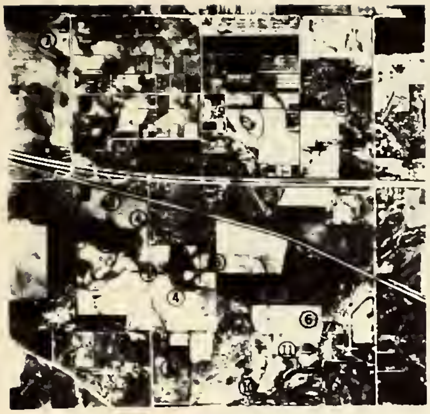
j. The imagery by University of Michigan Institute of Science and Technology, NASA Grant 715, permission by U. S. Army Electronics Command, Project MICHIGAN contract DA-28-043-AMC-00013(E).

Table 2. Qualitative Ratings of Various Film Types

Rating	Interpretation of Details[a]	Magnification[b]
Excellent	C-P, C-I	C-P, C-I, B&W (n)
Good	C-P/C-N	C-N, B-I (n)
Average	B&W, B-I	B&W, B-1
Poor	B&W/C-N	B&W/C-N, C-P/C-N

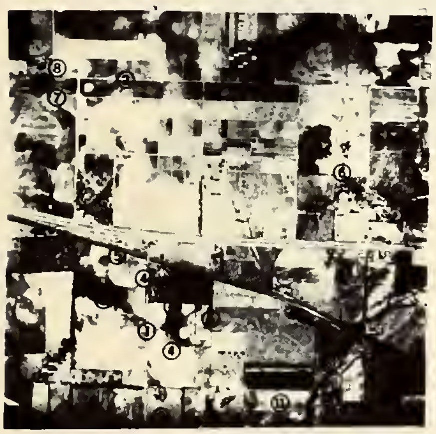
a - positive prints considered only

b - includes positives and negatives (n)



B & W

C - I



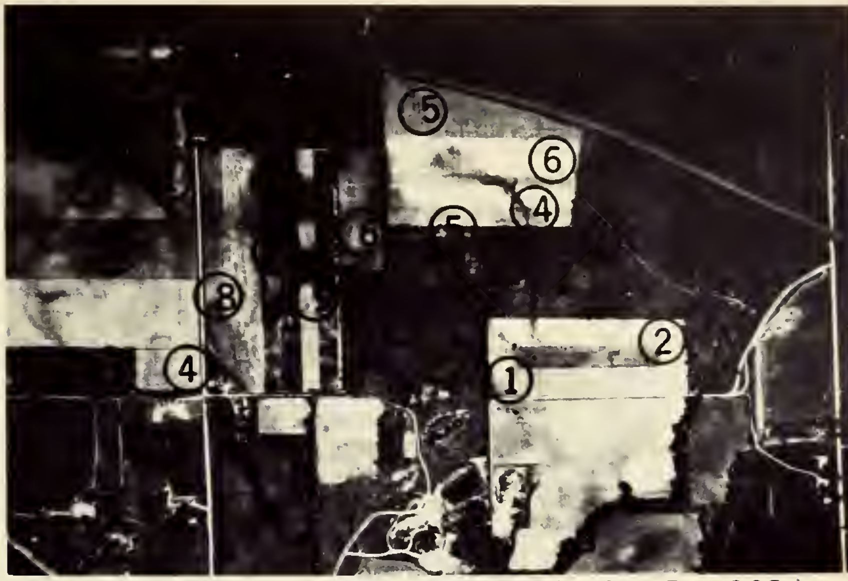
B - I

C - P

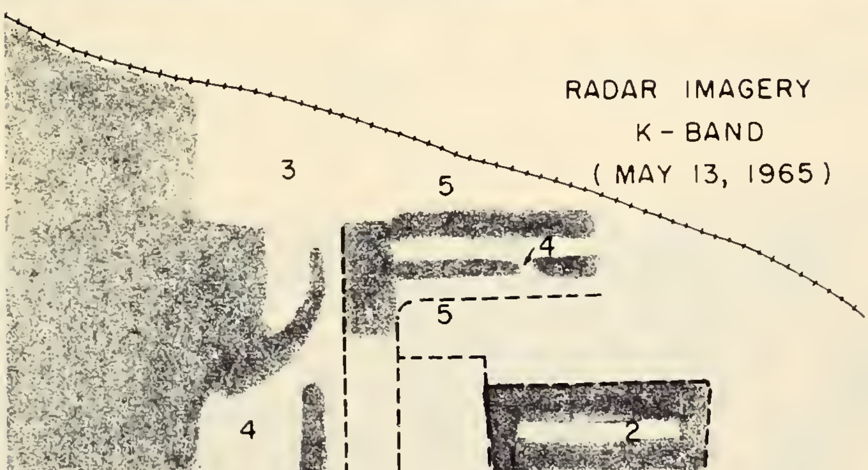
C - N

C - P/C - N

PLATE Ia. COMPARISON OF VARIOUS FILM TYPES (MAY, 1966).
(COLOR PHOTOGRAPHS AVAILABLE AT PURDUE UNIVERSITY)



AERIAL PHOTOGRAPH (MAY 13, 1965)



"ARTIST SKETCHES"

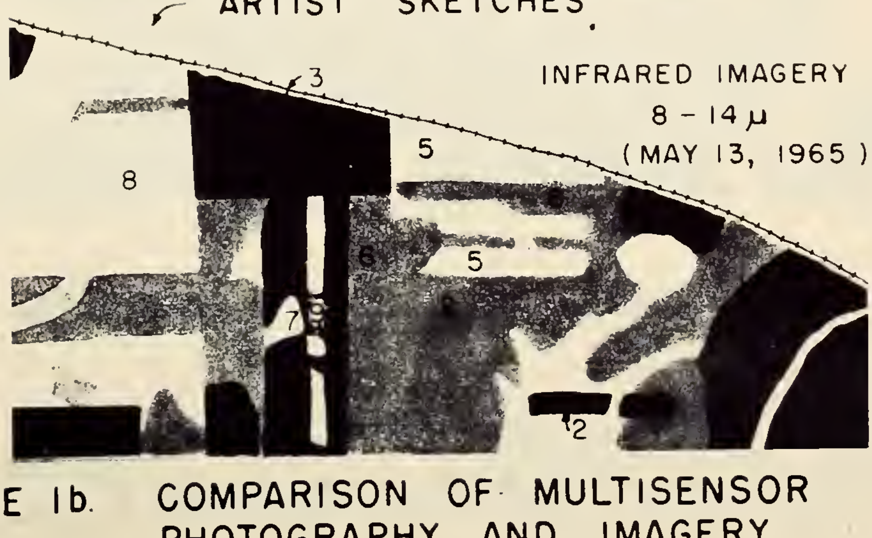


PLATE 1b. COMPARISON OF MULTISENSOR PHOTOGRAPHY AND IMAGERY.

DAYTIME IR 8 - 14μ (JUNE 2, 1966)

B & W PHOTOGRAPHY (MAY 2, 1966)

FIG. I COMPARISON OF VISUAL PHOTOGRAPHY AND INFRARED IMAGERY IN 8-14μ BAND

DAYTIME IR

8 – 14 μ

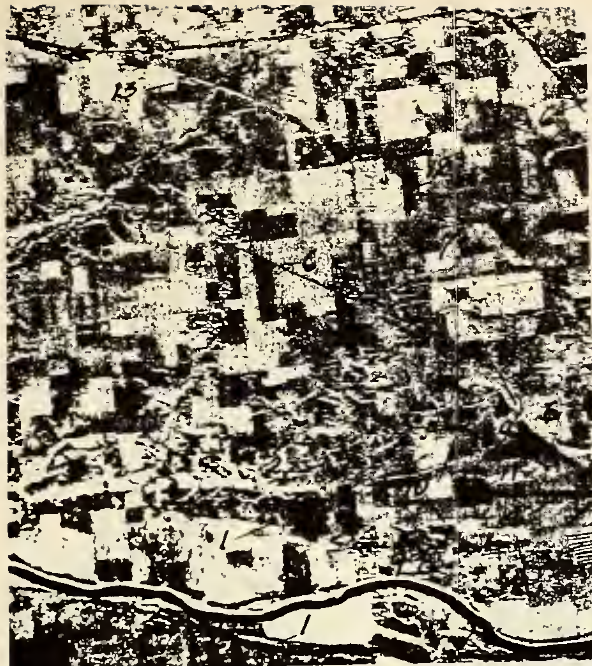
(JUNE 2, 1966)

NIGHTTIME IR

8 – 14 μ

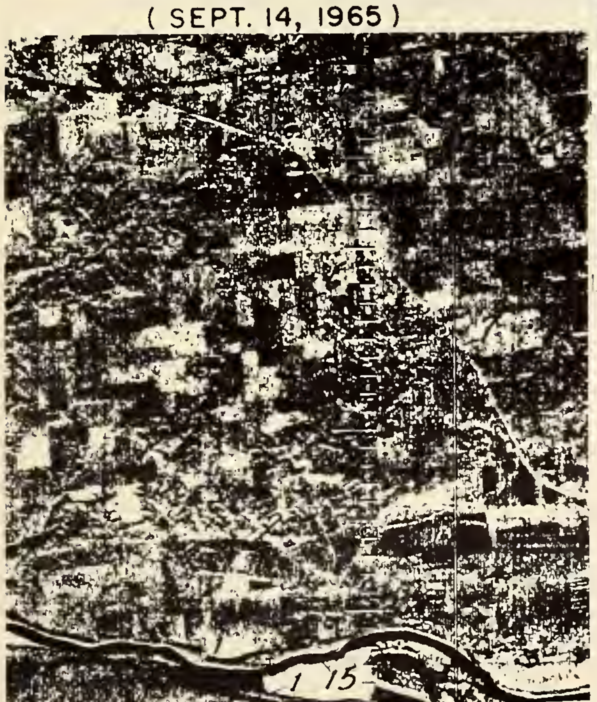
(JUNE [illegible], 1966)

FIGURE 2. COMPARISON OF DAYTIME AND NIGHTTIME INFRARED IMAGERY.



HH RADAR

(SEPT. 14, 1965)



HV RADAR

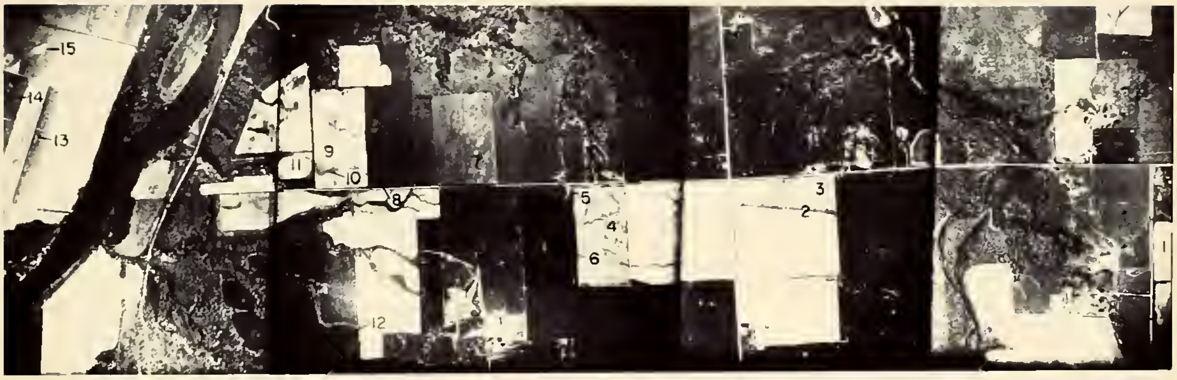
(SEPT. 14, 1965)

B&W PHOTOGRAPHY

(SEPT. 1, 1965)

FIGURE 3 COMPARISON OF VISUAL PHOTOGRAPHY AND HH AND HV RADAR IMAGERY.

B & W MOSAIC (MAY 6, 1966)



POINT	SOIL OR ROCK UNIT	CONDITION
1.	THICK LOESS/GLACIAL TILL	HIGH POSITION - BARE
2.	GLACIAL TILL	HIGH POSITION - PLOWING IN PROGRESS
3.	GLACIAL TILL	HIGH POSITION - RECENTLY PLOWED
4.	GLACIAL TILL	HIGH POSITION - PLOWED A FEW DAYS AGO
5.	SANDSTONE	SMALL EXPOSURE
6	GLACIAL TILL	COVERED WITH WINTER WHEAT
7	GLACIAL TILL/SANDSTONE	PASTURE, SANDSTONE EXPOSED IN PLACES
8	GLACIAL TILL, SANDSTONE	PASTURE
9	GLACIAL TILL	HIGH POSITION
10.	GLACIAL TILL	DEPRESSION
11.	GLACIAL TILL	HIGH POSITION
12.	GLACIAL TILL	COVERED WITH WINTER WHEAT
13.	FLOOD PLAIN	PLOWING IN PROGRESS
14.	FLOOD PLAIN	RECENTLY PLOWED
15.	SAND DUNES	BARE IN PLACES

FIGURE 4. LOCATION OF POINTS MEASURED ON MULTISPECTRAL IMAGERY.

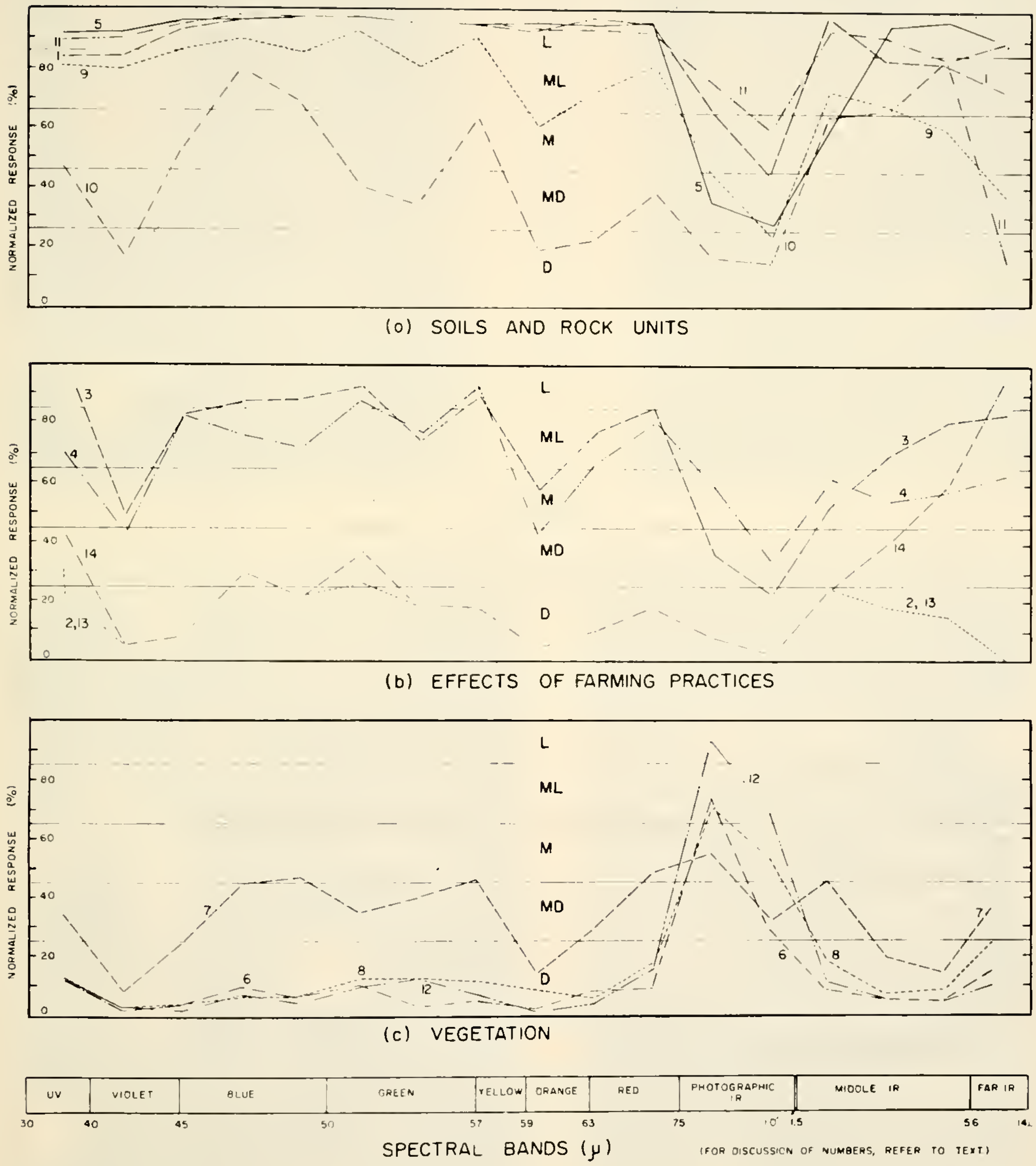
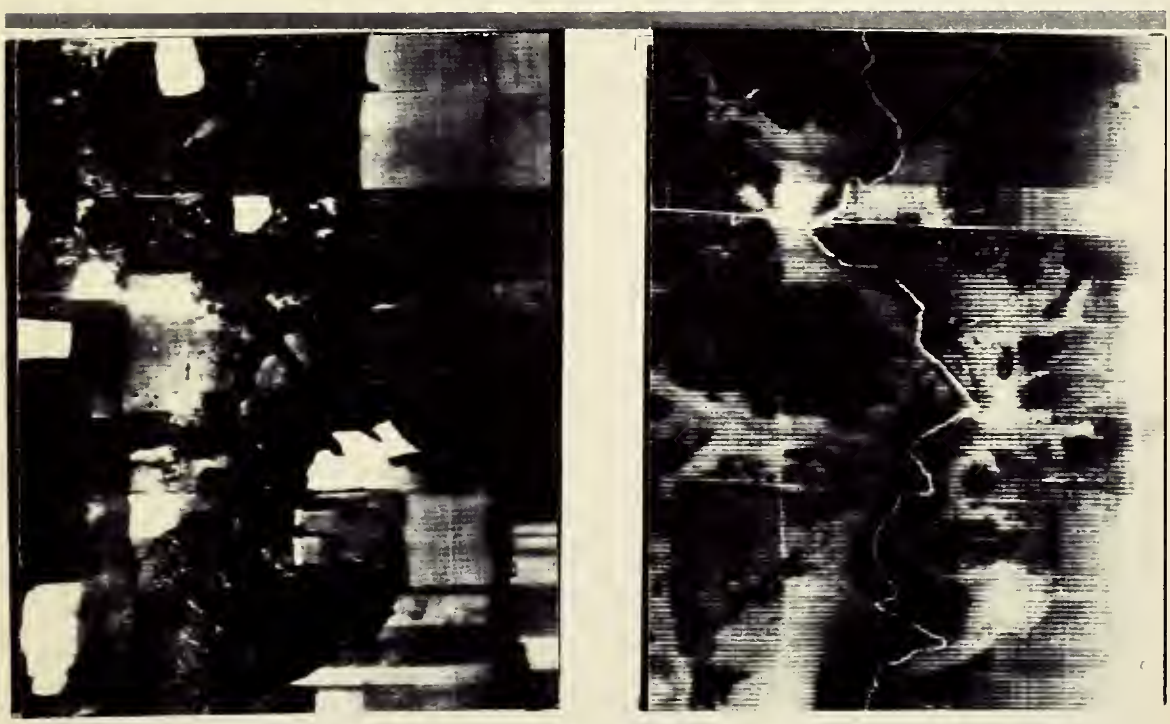


FIGURE 5. SPECTRAL RESPONSE SIGNATURES FOR VARIOUS FEATURES.

B-1 (MAY, 1966) B & W



IR DAYTIME (JUNE, 1966) IR NIGHTTIME

FIGURE 6. COMPARISON OF DRAINAGE PATTERNS EVIDENT ON PHOTOGRAPHY AND INFRARED IMAGERY.